GRAVITATIONAL WAVES, NEUTRINOS, AND NIELS BOHR

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Abstract: The radical idea that neutrinos are subatomic gravitational waves is presented. Given the available empirical evidence, as opposed to theoretical assumptions, this idea is not as bizarre and ignorable as it may at first sound.

I. BOHR'S QUESTION

"If at first an idea does not sound absurd, then there is no hope for it." *A. Einstein*

In 1933, not long after Pauli postulated the existence of the neutrino in order to preserve conservation of energy in beta decay processes, Niels Bohr raised the following question: "What is the difference between [neutrinos] and the quanta of gravitational waves?" At that time the neutrino was thought to have no mass or charge, and travel at the speed of light with almost no interaction with matter. These unusual properties were also theoretically predicted for gravitational waves. Subsequently, physicists have concluded that neutrinos have spin = 1/2, and that they can "flavor-shift" between different types of neutrinos. The latter phenomenon suggests that neutrinos have tiny masses and therefore cannot have v = c. So it would look like Bohr's question has been answered. While both gravitational waves and neutrinos should be ubiquitous in the cosmos, and can travel through gas, dust, stars, planets and whole galaxies largely unimpeded, they are thought to differ in spin (1/2 versus 2), mass, and speed.

On the other hand, nature has a history of serving up results that were previously considered "impossible". So maybe it is not unreasonable to take another look at Bohr's question. My interest in this question stems from a theory I have worked on for 40 years or so, called Discrete Scale Relativity [http://www3.amherst.edu/~rloldershaw]. For our present concern with gravitational waves and neutrinos, we need to mention DSR's main principle of discrete cosmological self-similarity. Roughly speaking this principle proposes that the cosmos is organized into discrete hierarchy of cosmological Scales, like the Atomic Scale, the Stellar Scale, and the Galactic Scale, which are all highly self-similar to one another. DSR also predicted in 1987 (Astrophys. J. **322**, 34-36, 1987) that the dark matter was composed of stellar mass black holes. This prediction was largely ignored in favor of WIMP candidates, but the positive

MACHO and LIGO results, combined with 30 years of negative results for WIMPs, has given increasing credibility to the idea that stellar-mass primordial black holes will solve the dark matter enigma.

In 2015 the LIGO collaboration observed gravitational waves for the first time, and now in conjunction with the VIRGO collaboration, several more gravitational wave events have been detected and characterized. So far the results have vindicated Einstein's General Relativity in all respects. It is now virtually certain that the cosmos is pervaded by astronomical numbers of these ghostly oscillations of space-time that are generated whenever stellar-mass ultracompact objects (black holes and neutron stars) interact strongly. The GWs travel at light speed, they have no charge or mass, and they can pass through matter like the Earth as if it were virtually transparent to them.

Another pair of key predictions of DSR propose that subatomic particles like protons, neutrons and nuclei are Kerr-Newman ultracompact objects (charged, rotating black hole solutions of the Einstein-Maxwell equations), and that the strength of gravitational interactions *within bound* subatomic systems is 10^{38} times stronger than was previously *assumed* without empirical verification. If the self-similarity principle of DSR is valid, then basically the same gravitational wave phenomena seen by LIGO/VIRGO on the Stellar Scale would have to be occurring on the Atomic Scale, which includes the atoms, ions and subatomic particles that we are very familiar with. Given the almost unimaginably large number of subatomic particles in the observable universe, DSR definitively predicts that vast numbers of subatomic GWs are passing through each centimeter of our world at the speed of light but interacting with matter only in extremely rare events. Is it possible that Bohr's question was prophetic and that neutrinos are these predicted subatomic GWs? Those who are experts in the Standard Model of Particle Physics would immediately rule out this idea as absurd since it is in flagrant conflict with what they have come to believe about the physics of the microcosm. However, if one looks solely at well-documented observations and remains scientifically skeptical of theoretical assumptions and untested theoretical modeling, then the case for Bohr's implied conjecture is far from closed.

II. MODEL-BUILDING AND THEORIES OF PRINCIPLE

"There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that it is the task of physics is to find out how nature <u>is</u>. Physics concerns what we can say about nature."   N. Bohr

"With four parameters I can fit an elephant, and with five and I can make him wiggle his trunk."
John von Newmann

Scientific theories can be divided into two categories: theories of principle and model-building theories. Special Relativity, General Relativity and Darwinian Evolution are considered theories of principle because they are founded upon and guided by fundamental principles which are postulated to be universal and close approximations to “how nature actually works”. Special Relativity invoked the principles that the velocity of light is a constant in all inertial reference frames, and that the laws of physics are the same in all inertial reference frames. General Relativity is founded on the principle that mass/energy modifies the geometry of space-time and objects move in paths that are determined by space-time geometry. Darwinian Evolution proposed the principles that there is natural variation in species, and that survival and reproductive success depended on an organism’s fitness. The fundamental principles of these theories are primarily conceptual, and they can be expressed in well-defined language, but they can also be codified, made more rigorous and further developed using analytical and mathematical methods. A key point is that these principles lead to definitive predictions wherein the theories can be empirically supported or contradicted with considerable confidence. Einstein famously said that if the 1919 eclipse experiment had not come out as General Relativity predicted, then the whole theory would have been ruled out.

Model-building theories are a horse of a different color. In these theories we start with a collection of observations and try to construct a model that can reproduce the observations in the simplest and most self-consistent manner. Concerning the theoretical physics that has taken place since the latter 1920s, the emphasis has been more on getting the right answer in a way that is mathematically elegant, and less on determining “how nature actually works”. Niels Bohr famously and candidly expressed this very idea while developing quantum mechanics. The associated “shut up and calculate” credo is quite popular among many theoreticians today. A key feature of model-building is that when new and sometimes unanticipated observations become available, the model is expanded to incorporate them. Further, when new observations conflict with the model, there is a concerted effort to adjust and/or modify the model until it once again becomes consistent with all observations. One problem with model-building theories is that they are harder to definitively test than theories of principle. Whereas latter’s fundamental principles are much more strict in what they will allow and what they will not allow, the flexibility of model-building means the one is often hard pressed to tell if changes to the theory are appropriate or are merely ad hoc fixes. An archetypal example occurred when Ptolemaic astronomers invoked epicycles to explain the retrograde motions of some planets. Many felt that this was elegant solution and virtually proved the model was correct. A few skeptics sensed an ad hoc fix that did not bode well for the model.

So let us mention a few specific characteristics of the Standard Model of Particle Physics, which are highly relevant to the topic under discussion here. This model-building effort is actually a set of models that have been developed over the last 70 years, or so. Even the most ardent proponents of the SMPP will grudgingly admit that it is a provisional model with some worrisome problems. These problems include, but are not limited to, the following:

1. The Standard Model is primarily a heuristic model with 26-30 fundamental parameters that have to be "put in by hand".

2. The Standard Model did not and cannot predict the masses of the fundamental particles that make up all of the luminous matter that we can observe.

3. The Standard Model did not and cannot predict the existence of the dark matter that constitutes the overwhelming majority of matter in the cosmos. The Standard Model describes the "foam on top of the ocean".

4. The vacuum energy density crisis clearly suggests a fundamental flaw at the very heart of particle physics. The VED crisis involves the fact that the vacuum energy densities predicted by particle theorists (microcosm) and measured by cosmologists (macrocosm) differ by up to 120 orders of magnitude (roughly 10^{70} to 10^{120}, depending on how one estimates the particle physics VED).

5. The conventional Planck mass is highly unnatural, i.e., it bears no relation to any particle observed in nature.

6. Many of the key particles of the Standard Model have never been directly observed. Rather, their existence is inferred from secondary, or more likely, tertiary decay products.

7. The Standard Model of Particle Physics cannot, as yet, be made compatible with the most fundamental and well-tested interaction of the cosmos: gravitation, i.e., General Relativity.

While the Standard Model of Particle Physics has been a very effective model that reproduces observations very well (albeit after decades of additions and adjustments), it is still a provisional model that should not be regarded as infallible. Given that it is scientifically reasonable and necessary to keep questioning our current understanding of the microcosm, let us objectively consider the four proposed falsifications of the idea that neutrinos are subatomic gravitational waves.

AN EXERCISE IN SCIENTIFIC SKEPTICISM

"In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual" *Galileo Galilei*

With this preamble on model-building and theories of principle, we are now ready for exploring whether or not the inference Bohr made 84 years ago regarding a possible relationship between neutrinos and gravitational waves deserves rehabilitation. Those who have studied and worked on the Standard Model of Particle Physics would forcefully deny any such relationship. They would agree that neutrinos are truly ubiquitous, uncharged, and pass virtually unscathed through matter at extremely high velocities, but they would claim that there are four properties of neutrinos that rule out any real connection between them and GWs. Firstly, the mixing of different types of neutrinos is viewed as proof that they have mass. Secondly, if they have mass then they cannot travel at the required speed of light. Thirdly, gravitation is far too weak in the subatomic realm to generate anything as energetic as neutrinos. Fourthly, neutrinos are known to have spins of 1/2, whereas GWs have spins of 2.

Let us scientifically question those four reasons for thinking that equating neutrinos and subatomic GWs is absurd.

(A) The Speed of the Neutrino

The apparent mixing of neutrino types as they travel from source to detector has theoreticians convinced that neutrinos must travel at speeds below the speed of light. However, when the speed of neutrinos is actually measured empirically, we get a quite different answer. One of the best tests of neutrino velocities came from the well known supernova SN1987A. When the blast was observed, physicists immediately searched neutrino detection data for coincident spikes in neutrino detections. A spike of 20 neutrinos correlated with SN1987A was detected. Timing analysis determined that any deviation from light speed for the arriving neutrinos was $< 2 \times 10^{-9}$ (i.e., $v > 0.999999998$ c). Then in 2014 Stecker et al. published a paper (Astroparticle Physics, **56**, 16-18, 2014; https://arxiv.org/abs/1306.6095) that used the 2010 Crab Nebula flare and the Ice Cube neutrino detector to limit any deviations of v from c to $< 5.6 \times 10^{-19}$. The most recent determination of possible deviation in neutrino speed v from c came from the MINOS Collaboration in 2015 (https://arxiv.org/abs/1507.04328) and gave the result $(v/c - 1) = (1.0 \pm 1.1) \times 10^{-6}$. Existing experimental results have led to the same answer: **there is no empirical evidence for v being anything other than c.**

(B) The Mass of the Neutrino

The results presented above already question the hypothesis that neutrinos have mass, since objects with mass cannot have v = c or their masses would be infinitely large. There also have been additional experimental results that have tested the massive neutrino hypothesis. A summary of observational and experimental results as of mid-October 2015 have been published by Palanque-Delabrouille (*Journal of Cosmology and Astrophysical Particles*, **11**, 011, 2015; https://arxiv.org/abs/1506.05976). Paraphrasing the main relevant result reported in their abstract: they find that *combining the BOSS Lyman-alpha data and the Planck CMB results* *constrains the **sum** of the masses of the three types of neutrino to **< 0.12 eV** (with 95% confidence limits).* That upper mass limit is approximately 2.35×10^{-7} times lower than the mass of the lightest known particle with mass – the electron. Continuing empirical inquiries into whether neutrinos do or do not have mass are currently underway by the KATRIN and MARE collaborations. In spite of the theoretical argument that neutrino mixing implies massive neutrinos, **to date there has been no observational or experimental result that has detected any mass for any type of neutrino.**

(C) Neutrino Energies

If the gravitational coupling factor was an absolute constant for all cosmological Scales, then the hypothesis that neutrinos are subatomic GWs would be untenable, since the gravitational interactions associated with nucleons and nuclei would be far too weak to generate detectable gravitational waves. However, there are two key facts that must be considered here. Firstly, the strength of gravitational interactions within bound subatomic systems has never been measured. Feel free to verify this for yourself; it is a fact (at least as of Oct 2017). Secondly, the scaling and self-similarity principles of Discrete Scale Relativity assert that values of the gravitational coupling factor (G) differ by a factor of approximately 10^{38} within bound systems on neighboring cosmological Scales. DSR predicts that **bound** subatomic systems have **interior** gravitational fields that are 3.27×10^{38} times larger than has always been *assumed*. The energies measured for SN1987A and the LIGO/VIRGO gravitational wave events are in the range of 4.5×10^{52} to 5.4×10^{54} ergs. Using the DSR scaling equations, which have never been adjusted because they are determined via a strict *principle*, we can predict that common neutrino energies from natural sources like supernovae and beta decays would have energies that are 1.70×10^{56} times less than those of the Stellar Scale GWs. This gives predicted energies in the range of 2.6×10^{-4} to 3.1×10^{-2} ergs, which are comfortably within range of roughly 2×10^{-7} to 2×10^{-1} ergs for relevant neutrino energies. The bottom line here is that **there is no inconsistency associated with the energies of neutrinos as long as the well-tested principles of DSR continue to be vindicated.**

(D) The Spins of Neutrinos and Gravitational Waves

This fourth potential impediment to the hypothesis that neutrinos are subatomic gravitational waves is the most difficult to deal with. It would be helpful if the spin of the neutrino could be empirically measured in a reasonably direct manner, but that is not possible – at least not yet. The fact that neutrinos are neutral particles means that straightforward spin determinations like the Stern-Gerlach experiment are not possible. Instead of direct observations, we must rely on **inferences** based on processes like beta decay and inverse beta decay. If these processes involve *exactly* what is assumed and nothing more, then a spin of 1/2 is required to conserve angular momentum, and no one wants to give up conservation of angular momentum. However, let us consider two spin determinations for very important particles: the electron and the proton.

Also requiring inference is the spin of the free isolated electron, which as of 2002 had never been measured (B. M. Garraway and S. Stenholm, *Contemporary Physics* **43**(3), 147-160, 2002). Previous experiments of the electron spin were based on electrons bound in atomic systems, such as silver atoms. A search of the literature up to the present time turned up no direct measurements of the free electron spin, only papers that claimed that this measurement was theoretically possible.

Then there is the strange story of the proton's spin. The Quark Model entered physics in the 1960s and proposed that the proton contained 3 quarks that had the bizarre property of fractional charges of -1/3 or 2/3. When heroic efforts to observe free quarks in nature relentlessly failed, theoretical physicists then added "confinement" to the model, which claimed that the quarks must be confined to the interiors of particles and so they could not be observed. The original stable of 3 quarks soon expanded to 6 quarks, 3 up-type and 3-down-type. Also a host of "gluon" particles necessary to glue (i.e., bind) the quarks together in subatomic particles were added to the model. Then came the introduction of hordes of "sea quarks", which are "*virtual*" quark/antiquark pairs that theoretically flit in and out of existence as the gluons decay and reform within the proton. This summary of the early model-building merely gives a small hint of the incredibly complicated and convoluted development of the quark model of the proton. Anyone who wants an objective and highly detailed recounting of the first 2 decades of quark model-building should read Andrew Pickering's book *Constructing Quarks* (University of Chicago Press, Chicago, 1984). In 1987 European Muon Collaboration conducted an experiment to determine details of how the spin of the proton was generated by the 3 real quarks inside the proton, sometimes called the valence quarks, which were supposed to contribute most of the proton's spin. Unexpectedly, the valence quarks only accounted for 4% to 24% of the spin. The mystery of where all the rest of the spin was coming from was called the "proton spin crisis". After 30 years of tinkering with the Quark Model there is now a claim that the proton spin has been "explained" (Alexandrou, et al., *Physical Review Letters* **119**, 142002, 2017). The proposed explanation using lattice QCD involves contributions from the valence quarks, gluons, and sea quarks, as well as use of the pion mass to estimate the quark masses, renormalization procedures to help reduce statistical errors of various contributions to the angular momentum, and a considerable amount of time running the *simulations* on a supercomputer. This brief summary is a highly abridged hint of the amazing complications and contortions involved in the effort to "explain" the spin of the proton. It would be understandable for a skeptic to say: "If you know the specific answer you want, then there is always a way, or several ways, to get that answer in model-building exercises."

It is my opinion that at some time in the future we will have a very different understanding of the physics of the microcosm, and that it will be dominated by General Relativity. It will be a theory of principle that is even more successful than the Standard Model of Particle Physics in reproducing subatomic and atomic phenomena in a way that will be far more elegant and natural.

Whereas the putative neutrino/gravitational wave spin disparity issue may take a long while to sort out. We do have two much more readily available empirical tests of the proposed hypothesis that neutrinos are subatomic gravitational waves: (1) whether or not v = c for neutrinos, and (2) whether neutrinos really have mass or whether they are massless, as originally thought. Answers to these two questions should come in the foreseeable future and will either falsify the hypothesis implied in Bohr's question, or allow it to remain viable. Another possible definitive test of the hypothesis is conceivable if we could somehow figure out a way to look for correlated neutrino detections at widely separated detectors. These correlations are clearly expected for gravitational waves and have been observed by LIGO/VIRGO, but they would not be expected for conventional SMPP neutrinos.

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